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Temporal and spatial variation of phytoplankton composition and abundance to determine water quality in Nanjiang Reservoir, China

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ABSTRACT

Understanding the temporal and spatial dynamics of phytoplankton is crucial for assessing water quality in freshwater ecosystems. In this study, the temporal and spatial distribution of phytoplankton and its correlation with environmental factors were studied during the Summer and Autumn of 2022 in the Nanjiang Reservoir, China, to determine its water quality. Water sampling was conducted monthly for 5 months at four fixed sites along the reservoir. Phytoplankton species composition and abundance were analysed based on the Utermöhl method while the physico-chemical parameters were analysed based on standard methods. The study identified 198 species, 74 genera, and 7 phyla (*Bacillariophyta, Chlorophyta, Cyanophyta, Euglenophyta, Dinophyta, Cryptophyta, and Chrysophyta*) in the reservoir. Bacillariophyta displayed the greatest cellular abundance and species diversity during the study period. The average abundance of phytoplankton in summer (217.76 ± 13.59) × 10^4 cells/L was higher than that in autumn (178.93 ± 13.59) × 10^4 cells/L. The upstream of the reservoir represented the highest phytoplankton density, biomass, and diversity attributable to the highest concentrations of nutrients from the river's influx observed in the same section. Correlation and Redundancy analysis (RDA) highlighted water temperature, pH, and total dissolve solid (TDS) as the most important environmental factors influencing phytoplankton community structure. These findings highlight the importance of monitoring phytoplankton dynamics as a reliable indicator of water quality in reservoirs and may have implications for Nanjiang Reservoir management and conservation efforts.

Keywords: China, Nanjiang Reservoir, water quality, phytoplankton community, redundancy analysis (RDA).

INTRODUCTION

Phytoplankton, a biological assemblage consisting of eukaryotic algae and prokaryotes, are one of the major components of aquatic environments and play crucial roles in regulating the balance of aquatic ecosystems (Lin *et al.*, 2024). As the most important primary producers in these environments, changes in the phytoplankton community structure affect higher trophic level organisms hence impacting the structure and function of the entire aquatic ecosystem (Chen *et al.*, 2016). Changes in phytoplankton structure and distribution emanate from changes in physico-chemical variables such as pH, dissolved oxygen, water temperature, chemical oxygen demand, and nutrient concentrations (Wu *et al.*, 2022). Notably, these environmental factors cause variations in species composition, dominant taxa, relative abundance, and the succession of the phytoplankton community (Stephene, 2020). Due to their important roles in primary productivity, nutrient cycling, and sensitivity to environmental changes, phytoplankton are vital biological indicators for monitoring water quality in aquatic environments (Reynolds, 2006; Lin *et al.*, 2024). They also serve as important indicators of the health of aquatic environments and serve as valuable guidelines for ensuring the preservation of water biological systems (Carvalho *et al.,* 2013; Nankabirwa *et al.,* 2019).

Like in other parts of the world, numerous water bodies in China still suffer from eutrophication and heavy metal problems (Huang *et al.*, 2022), arising from the effects of rapid economic development and population growth in recent years. Eutrophication of lakes and reservoirs can lead to short-term algal blooms which degrade water quality by decreasing dissolved oxygen concentration in water, increasing pH, temperature, and salinity conditions (Goswami *et al.*, 2020; Wu *et al.*, 2022; Wang *et al.*, 2024). Large-scale algal overgrowth can be detrimental to the health of humans and aquatic organisms (Liu *et al.*, 2014; Chao *et al.*, 2022), and economic growth (Yan *et al.*, 2022). For example, within a short period after cyanobacteria bloom, the massive proliferation of cyanobacteria releases toxic substances into the water which when ingested by humans results in severe damage to liver function (Zhang *et al.*, 2022). Also, many cyanobacteria accumulate on surfaces, affecting the light and respiration of fish and other aquatic organisms, and worse, causing fish death due to hypoxia (Zhiwen *et al.*, 2006). Not only does the surface layer have a serious impact on the environment of tourist areas, but the stench produced after the death of blue-green algae is even more serious (Wang *et al.*, 2021). Due to these reasons, it's necessary to strengthen the water quality monitoring and restoration efforts in eutrophication-vulnerable Chinese water bodies.

Previous water quality studies in China have frequently focused on the variations in phytoplankton structure within eutrophic rivers and lakes to support restoration efforts (Huang *et al.*, 2022; Qu and Zhou, 2023; Zhang *et al.*, 2024). However, less attention has been given to eutrophication-prone reservoirs located in major cities. Consequently, the impact of environmental factors on the phytoplankton community structure in many of the country's reservoirs remains largely unexplored. The Nanjiang Reservoir, situated in the south-western region of China, is a critical freshwater body located in the province of Zhejiang serving multiple purposes including water supply, irrigation, flood control, and hydropower generation. Over the years, human activities such as agriculture, urbanization, and industrialization in or near the Nanjiang Reservoir have increased, and this could impact the water quality dynamics and ecosystem health of the reservoir (Li *et al.*, 2022). However, analyses of the Nanjiang Reservoir's phytoplankton communities' temporal and geographical variability in relation to environmental factors have not yet been comprehensively reported. Therefore, this study focuses on analysing the temporal and spatial variation of phytoplankton composition and abundance to determine water quality in Nanjiang Reservoir. More specifically, the study examines the temporal and spatial variability of phytoplankton abundance, species composition, and diversity in relation to selected physico-chemical parameters over a defined period. In so doing, the study seeks to offer insights that would be helpful in predicting the occurrence of phytoplankton blooms and would serve as a foundation for informed decision-making in the preservation and sustainable management of this vital water resource. These kinds of research are crucial for guiding management plans intended to protect China's reservoir resources' ecological integrity and sustainable use.

METHODS

Study area

The Nanjiang Reservoir (Figure 1) is a significant freshwater body located in China, serving multiple purposes including water supply, irrigation, flood control, and hydropower generation. The Nanjiang Reservoir is situated in the south-western region of China, specifically in the province of Zhejiang. It is nestled within the Nanjiang River basin, which is a tributary of the larger Yangtze River system. The reservoir plays a crucial role in water resource management, providing water for domestic, agricultural, and industrial purposes in the surrounding region (Zhang *et al.*, 2010). Additionally, it contributes to flood control efforts, helping to mitigate the impact of seasonal flooding in the downstream areas (Li *et al.*, 2017). The reservoir's hydropower generation capacity also contributes to the region's energy needs. As a freshwater ecosystem, the Nanjiang Reservoir supports diverse flora and fauna, including phytoplankton, fish species, and aquatic plants. The ecological health of the reservoir is closely linked to its water quality, making it an area of interest for environmental monitoring and conservation efforts. Human activities such as agriculture, urbanization, and industrialization in the surrounding areas can impact the water quality and ecosystem health of the reservoir (Wang, *et al.,* 2020). Efforts to mitigate pollution and maintain sustainable water management practices are important for preserving the reservoir's ecological integrity.

Figure 1 Displays a map, highlighting the location of the research area within China, and monitoring sites strategically selected to reflect the reservoir's hydrological intricacies. We strategically placed these sites at the tributaries or confluences of important rivers, as well as in straight river sections with stable riverbeds, consistent water flow conditions, wide water surface, and no shoals. Nanjiang Reservoir features four monitoring sites: S1, positioned downstream of the dam; S2 and S3, situated in the middle of the reservoir; and S4, located at the upstream inlet of the reservoir.

Sampling and analyses

We meticulously carried out the monthly sampling for this investigation throughout five months, sampling from June 2022 to October 2022. The sampling protocol targeted four strategically chosen fixed sites, as illustrated in Figure 1. This systematic selection ensured representation across the reservoir's spatial diversity and encompassed critical seasonal variations, covering the summer months (June, July, and August) and the autumn months (September, and October) in China. The choice of a five-month sampling duration aimed to capture the dynamic changes in phytoplankton composition and abundance and physico-chemical variables across distinct seasonal shifts. The inclusion of both summer and autumn seasons recognizes the potential influence of varying environmental conditions on phytoplankton dynamics during critical periods. This comprehensive temporal approach enhances the robustness of the dataset, proving a nuanced understanding of how phytoplankton responds to varied environmental factors in each season within Nanjiang Reservoir.

At each sampling site, measurements of water temperature (°C), dissolved oxygen (mgL^{-1}), conductivity (μScm^{-1}), pH, TDS (mgL^{-1}), depths (m), and turbidity (NTU) were performed in-situ using a portable multiparameter probe (YSI Professional Plus). Additionally, water samples were collected at each sampling site and quickly delivered the sample to Shanghai Ocean University's Ecological Laboratory for same-day analysis of nutrients and phytoplankton examination. The nutrients − total nitrogen (TN), total phosphorus (TP), nitrate-nitrogen (NO_2-N), nitrite-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), and potassium manganate (VII) ($KMnO_4$) − were analyzed in the laboratory based on American Public Health Association (2017) standard methods for the examination of water and wastewater.

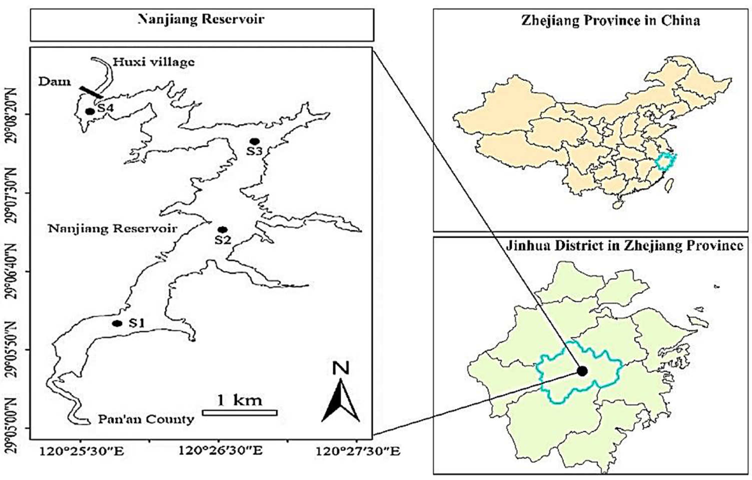

Figure 1. Study area and locations of the sampling 4 sampling sites

The methodology employed for phytoplankton collection was systematic. A 5L Peterson water sampler was used to collect 1 L water samples from four fixed sites, as depicted in Figure 1. At each collection site, the samples were carefully stored in sample bottles and promptly treated with Lugol's iodine reagent for preservation. Upon arrival at the laboratory, the fixed samples underwent a standardized procedure. After allowing the samples to settle for 48 hours, the supernatant was carefully siphoned off, and the sample volume was adjusted to 30 mL for further analysis. Phytoplankton species identification was conducted using an Olympus CX31 optical microscope (Olympus, Tokyo, Japan) at 400x magnification, following the taxonomic guidelines outlined by Hu *et al.* (1980). Colonial organisms, such as *Merismopedia*, were counted as single colonies, a common practice for colonial species that form clusters, as they are typically observed as cohesive units in surface waters. A thorough count at the species level was performed using a 3 mL Sedgwick-Rafter counting chamber to ensure a representative assessment of the phytoplankton community. To obtain accurate biomass data, a minimum of 20 cells were examined for each taxon. The geometric shape closest to the cell morphology was used to calculate the mean biovolume, which was then converted to biomass (expressed in mg/L) following the methodology outlined by Helbling *et al.* (1992). Following the identification of phytoplankton to the most granular taxonomic level possible (genus/species), four diversity indices – dominance index, Shannon-Wiener diversity, Pielou's species evenness, and Margalef's species richness were computed using established formulas. The utilization of standardized protocols and references ensured the reliability and comparability of the phytoplankton data collected from Nanjiang Reservoir during the specified sampling period:

The dominant species of phytoplankton were identified by calculating the dominance index (Y) for each species (Lampitt *et al.*, 1993).

$$Y = Ni/N \times f \quad (1)$$

where: Ni represents the abundance of the ith species, N is the total abundance of all species, and f denotes the frequency of occurrence of the ith species. A species is considered dominant when Y > 0.02.

The Shannon-Wiener index formula (Shannon and Weaver, 1948).

$$H' = -\sum(Ni/N)\ ln\ (Ni/N) \quad (2)$$

Pielou's evenness index (J') formula (Pielou, 1966).

$$J' = H'/lnS \quad (3)$$

Margalef's richness index (D') formula (Lampitt *et al.*, 1993).

$$D = (S - 1) / \log_2 N \quad (4)$$

where: Pi – the proportion of individuals, calculated as the abundance of an individual species divided by the total number of individuals in the sampled community, ln – the natural logarithm, ΣΣ – the sum of all calculations, S – the total number of species, N – the total number of individuals in the sample, H – Shannon-Wiener index of diversity, d – Margalef's richness index.

Following the completion of both sampling and laboratory analyses, the acquired data were organized using Microsoft Excel 2021 and subjected to analysis utilizing the Statistical analyses were conducted using an Excel spreadsheet program. Differences in parameter variation across distinct sampling sites and months were assessed through the ANOVA method, employing a predetermined *p-value* of ≤ 0.05. Additionally, variation during different sampling seasons were examined using an independent t-test, also with a predetermined *p-value* ≤ 0.05. In instances where a significant difference was detected using ANOVA, post hoc analyses were conducted to further explore specific variations. In CANOCO version 5, redundancy analysis (RDA) was employed to elucidate relationships between species and environmental factors across various sites (Smilauer and Leps, 2014; Ter Braak *et al.*, 2018). Preceding the RDA, both species and environmental datasets underwent transformation using log (X + 1). Normality assumptions for the transformed data were assessed using the Kolmogorov-Smirnov test (Kozak *et al.*, 2020).

RESULTS

Characteristics of the phytoplankton community structure

A graphical depiction of the mean phytoplankton species composition in Nanjiang Reservoir is shown in Figure 2. During the period between June 2022 and October 2022, the phytoplankton community in the reservoir generally comprised of Bacillariophyta, Chlorophyta, Cyanophyta,

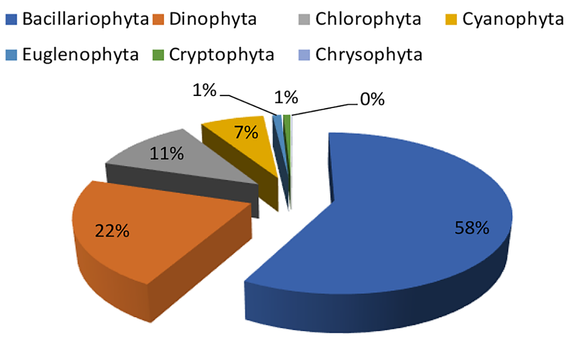

Figure 2. Phytoplankton species composition in Nanjiang Reservoir

Euglenophyta, Dinophyta, Cryptophyta, and Chrysophyta, and amounting to a total 198 species spread across 74 genera. Among these, Bacillariophyta displayed the highest species diversity, comprising 20 genera and 48 species, which accounted for 58% of the entire community in the reservoir. This was followed by Dinophyta comprising 4 genera and 10 species (22%). Following closely, Chlorophyta contributed 21 genera and 78 species, representing 11% of the community, while Cyanophyta constituted 19 genera with 42 species, making up 7%. The phytoplankton groups Euglenophyta and Cryptophyta were relatively rare, collectively contributing 2% to the overall community. Remarkably, Chrysophyta, represented with only 3 species from 2 genera, had the lowest representation in the reservoir.

Dominant phytoplankton species in Nanjiang Reservoir

A total of 16 dominant species were identified in Nanjiang Reservoir, as presented in Table 1, where species with a dominance degree (Y) greater than 0.2 were classified as dominant. The identified dominant species remained largely consistent across different periods in Nanjiang Reservoir. In the summer season, six dominant species were recognized, namely *Synedra ulna, Melosira granulata ansgustissima, Coelastrum microporum, Aphanocapsa spp, Pseudanabaena limnetica,* and *Merismopedia tenuissima.* Similarly, during the autumn season, another set of six dominant species emerged, including *Scenedesmus quadricauda, Dolichospermum flos-aquae, Synedra acus, Aphanizomenon spp, Microcystis flos-aquae,* and *Pseudanabaena limnetica.* This consistency in dominant species across seasons underscores the stability and resilience of the phytoplankton community in Nanjiang Reservoir.

Phytoplankton density and biomass in Nanjiang Reservoir

Phytoplankton density

The overall mean phytoplankton density in Nanjiang Reservoir was ($203.12 \pm 9.12 \times 10^4$ cells/L). Site S2 exhibited the lowest mean phytoplankton density at ($190.94 \pm 12.92 \times 10^4$ cells/L),

Table 1. Phytoplankton dominant species in Nanjiang Reservoir

Season	Species	Strength
Summer	Synedra acus	0.19
	Synedra ulna	0.12
	Pseudanabaena limnetica	0.09
	Melosira granulata angustissima	0.09
	Coelastrum microporum	0.09
	Merismopedia tenuissima	0.06
	Scenedesmus acuneae	0.07
	Aphanocapsa	0.05
Autumn	Microcystis flos-aquae	0.27
	Aphanizomenon	0.22
	Dolichospermum varibilis	0.13
	Dolichospermum flos-aquae	0.13
	Aphanocapsa	0.12
	Synedra acus	0.09
	Pseudanabaena limnetica	0.05
	Scenedesmus quadricauda	0.05

while site S4 had the highest density at (247.57 ± 27.88 × 10^4 cells/L) (Figure 3). No significant spatial variation was observed in the mean phytoplankton density in Nanjiang Reservoir, as indicated by ANOVA (F (3.89) = 1.368, p = 0.258). Regarding temporal variation, the lowest mean phytoplankton density of (151.94 ± 8.05 × 10^4 cells/L) was recorded in October 2022, while the highest mean of (237.13 ± 32.67 × 10^4 cells/L) was observed in June 2022. ANOVA analysis indicated no significant temporal variation ($p < 0.05$) in the mean phytoplankton density values in Nanjiang Reservoir (F (4.88) = 2.865, p = 0.028). Notably, there was a decreasing trend in the mean overtime during the sampled months (Figure 3). Seasonally, the average phytoplankton density during the summer season (217.76 ± 13.59 × 10^4 cells/L) exceeded that of the autumn season (178.93 ± 13.59 × 10^4 cells/L) during the sampling period. The T-test analysis indicated no significant variation in the average phytoplankton density between the two seasons (t (91) = 2.055, p = 0.000). These findings highlight that the summer season exhibited a higher abundance of individuals compared to the autumn season.

Phytoplankton biomass

At the spatial scale, the biomass in Nanjiang Reservoir exhibited an overall mean of 0.52 ± 0.05 mg/L. Site S1 recorded the lowest mean value (0.43 ± 0.09 mg/L), while the highest mean value (0.72 ± 0.13 mg/L) was observed at site S4. However, ANOVA analysis indicated no statistically significant difference ($p < 0.05$) in the mean biomass values among the sampled sites (F (3.89) = 1.111, p = 0.349) (Figure 4). On the temporal scale, the biomass in Nanjiang Reservoir exhibited an overall mean of 0.52 ± 0.05 mg/L. The lowest mean value 0.29 ± 0.04 mg/L, was observed in September 2022, while June recorded the highest mean value of 0.99 ± 0.20 mg/L. The mean biomass demonstrated a general decreasing trend over the sampled months (Figure 4), and the ANOVA (at $p < 0.05$) indicated a significant difference in the mean biomass values among the sampled months (F (4.88) = 6.708, p = 0.000). Seasonally, the mean biomass of the summer season (0.65 ± 0.08 mg/L) surpassed that of the autumn season (0.031 ± 0.04 mg/L) during the sampling period. An additional

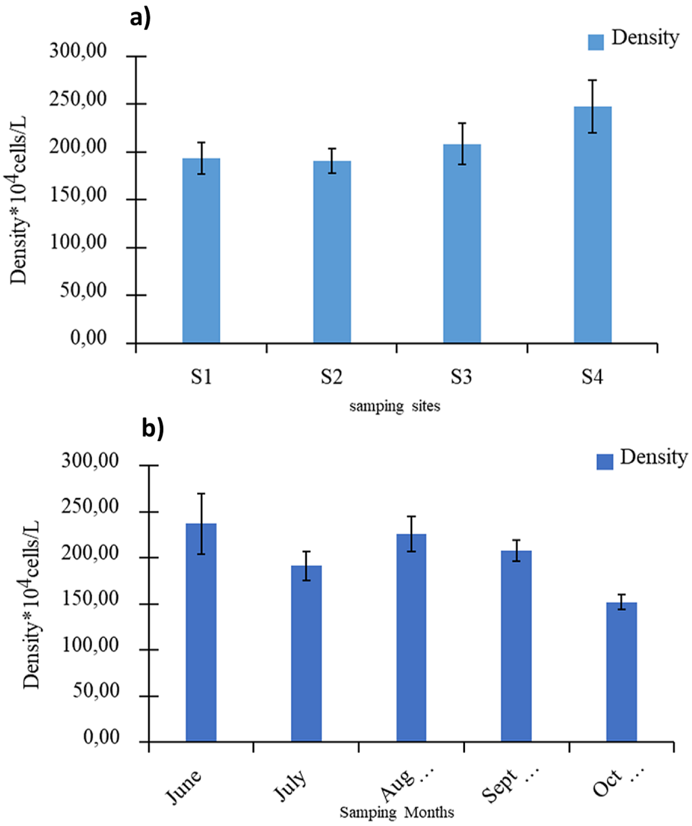

Figure 3. Spatial and temporal distribution of phytoplankton density at Nanjiang Reservoir, sampling sites (a) and sampling months (b)

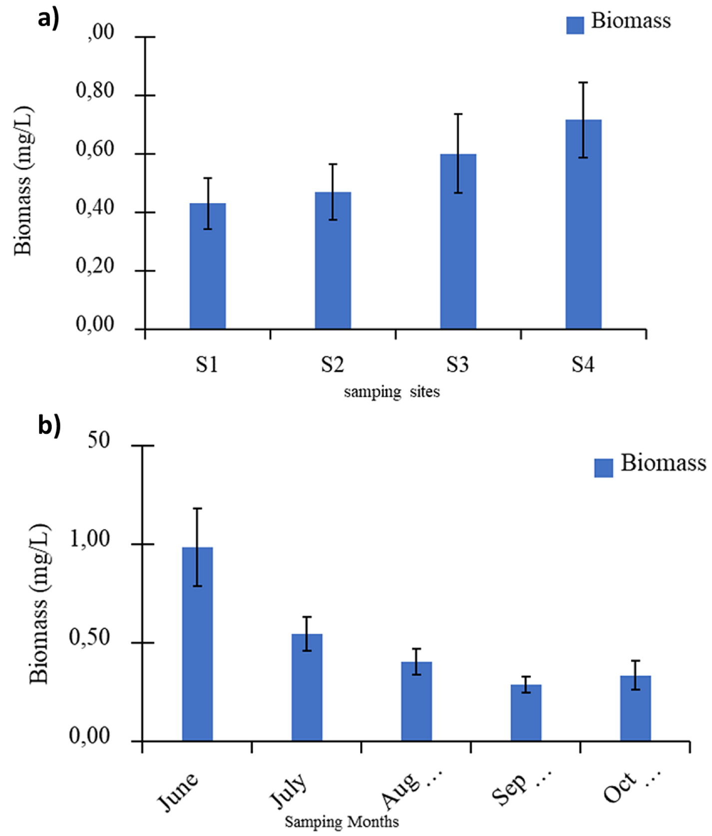

Figure 4. Spatial and temporal distribution of phytoplankton biomass at Nanjiang Reservoir, sampling sites (a) and sampling months (b)

comparison of the mean biomass values using an independent T-test revealed no significant difference ($P < 0.05$) between the summer and autumn seasons ($t(91) = 3.147$, $p = 0.000$).

Temporal and spatial fluctuations in phytoplankton species diversity indices

Diversity serves as a crucial indicator of ecosystem health, and diversity indices are indispensable tools for evaluating this health by comprehending community structure. In assessing the phytoplankton species diversity of the reservoir, the diversity indices were employed: Shannon-Wiener diversity, Pielou's evenness, and Margalef's richness. Overall, the reservoir exhibited substantial temporal and spatial diversity. The outcomes detailing the spatial and temporal variations of these indices are outlined in Table 2.

In our study investigating the temporal and spatial variation of phytoplankton composition and abundance in Nanjiang Reservoir, China, we observed significant fluctuations in the average Shannon-Wiener diversity index. The index ranged from a minimum of 2.58 in autumn to a maximum of 2.68 in summer. Site S4, located upstream of the reservoir, exhibited the highest measured diversity index of 2.86, while site

Table 2. Summary of seasonal variation in phytoplankton diversity in Nanjiang Reservoir

Seasonal		Shannon-Wiener	Evenness index	Richness index
Summer	Mean	2.68[a]	0.83[a]	5.25[a]
	SE	0.04	0.01	0.16
Autumn	Mean	2.58[a]	0.87[a]	3.97[a]
	SE	0.04	0.00	0.12
Total	Mean	2.61	0.84	4.74
	SE	0.03	0.01	0.13

Note: mean values in the same column with different superscript letters are significantly different.

S2 downstream had the lowest index of 2.53. Combining data from both seasons, the average diversity index was 2.64. Similarly, the average evenness index varied, with a minimum of 0.83 in summer and a maximum of 0.87 in autumn. Site S2 had the lowest measured evenness index at 0.83. Regarding richness, the highest index of 5.25 was observed in summer, while the lowest index of 3.97 was recorded in autumn. These findings provide valuable insights into the variations in phytoplankton community structure and abundance, contributing to our understanding of water quality in Nanjiang Reservoir.

Analysis of the physico-chemical environmental parameters in Nanjiang Reservoir

Spatial and temporal variations in physico-chemical parameters

The physico-chemical characteristics of Nanjiang Reservoir's water bodies in 2022 are detailed in (Table 3). Throughout the research period, Nanjiang Reservoir experienced fluctuating water levels, spanning a range of 35 m. Notably, water temperature, a key hydrographic factor influencing various chemical and biological interactions, exhibited significance. The mean water temperature across all measurements stood at 24.32 °C. ANOVA analysis ($p < 0.05$) indicated no significant differences between the four sites of Nanjiang Reservoir. Despite this, the upstream site recorded the highest mean water temperature (26.26 °C), while the downstream site recorded the lowest (23.70 °C) with (F (3.89) = 1.739, p = 0.165. Seasonal comparison using an independent t-test showed no statistically significant difference ($p < 0.05$) (t (91) = -0.670, p = 0.236) between autumn and summer periods. Regarding pH levels, site S4 exhibited the highest value, while site S2 showed the lowest. Nevertheless, ANOVA analysis ($p < 0.05$) (F (3.89) = 2.937, p = 0.038) revealed a significant difference in mean pH values across the sampled sites. Seasonal variation in mean pH values was also evident, with a separate t-test (t (91) = 2.057, p = 0.000) indicating significant differences ($p < 0.05$) between summer and autumn sampled periods. Total nitrogen averages varied between site S1 (minimum) and site S4. Similarly, ammonia nitrogen levels reached their peak at site S4 and were lowest at site S3.

Pearson correlation (r) among physicochemical parameters

Correlation analysis (refer to Table 4) revealed positive associations between dissolved oxygen and pH in the environment with water temperature (WT). Additionally, total nitrogen and nitrogen and nitrate nitrogen exhibited negative correlation with water temperature. Nitrite nitrogen, on the other hand, showed positive correlations with dissolved oxygen, pH, and total phosphorus (TP). Furthermore, total dissolved solids demonstrated a correlation with conductivity. These findings underscore the significance of the water quality

Table 3. Season variations in the physical and chemical variables (mean ± SE) within Nanjiang Reservoir during the summer and autumn seasons

Parameters	Summer season	Autumn season	P-Value
WT (℃)	24.35 ± 0.62^a	24.27 ± 0.31^b	0.000
DO (mgL^{-1})	4.68 ± 9.32^a	4.73 ± 0.39^b	0.004
Conductivity (μScm^{-1})	93.91 ± 0.99^a	102.74 ± 1.12^b	0.327
pH	7.55 ± 0.09^a	7.33 ± 0.07^b	0.000
TDS (mgL^{-1})	61.05 ± 0.65^a	66.81 ± 0.72^b	0.431
Depths (m)	24.74 ± 0.97^a	22.77 ± 1.57^b	0.552
Turbidity (NTU)	4.73 ± 0.97^a	5.60 ± 2.51^b	0.236
TN (μgL^{-1})	1.26 ± 0.04^a	1.03 ± 0.07^b	0.496
TP (μgL^{-1})	0.04 ± 0.01^a	0.04 ± 0.01^b	0.795
NO_2-N (μgL^{-1})	0.01 ± 0.00^a	0.01 ± 0.00^b	0.714
NO_3-N (μgL^{-1})	0.36 ± 0.01^a	0.34 ± 0.04^b	0.634
NH_3-N (μgL^{-1})	0.36 ± 0.01^a	0.22 ± 0.02^b	0.443
$KMnO_4$ (μgL^{-1})	3.38 ± 0.01^a	3.09 ± 0.15^b	0.272

Note: mean values in the same row with different superscript letters are significantly different.

Table 4. Pearson correlation analysis among physicochemical parameters in Nanjiang Reservoir

Variable	WT	DO	COD	TDS	pH	Turb	TN	TP	NO_3-N	NO_2-N
WT	1									
DO	0.559**	1								
COD	0.205*	0.161	1							
TDS	0.202	0.163	0.998**	1						
pH	0.771**	0.866**	0.034	0.039	1					
Turb	-0.066	0.007	-0.054	-0.056	-0.131	1				
TN	-0.435**	-0.072	-0.250*	-0.242*	-0.195	0.025	1			
TP	-0.260*	0.176	0.028	0.021	0.025	0.032	0.259*	1		
NO_3-N	-0.508**	-0.316**	-0.449**	-0.451**	-0.394**	0.126	0.553**	0.078	1	
NO_2-N	0.043	0.411**	0.049	0.050	0.272**	0.041	0.225*	0.314**	-0.002	1

Note: ** shows correlation is significant at the 0.01 level (2-tailed); * shows correlation is significant at the 0.05 level (2-tailed).

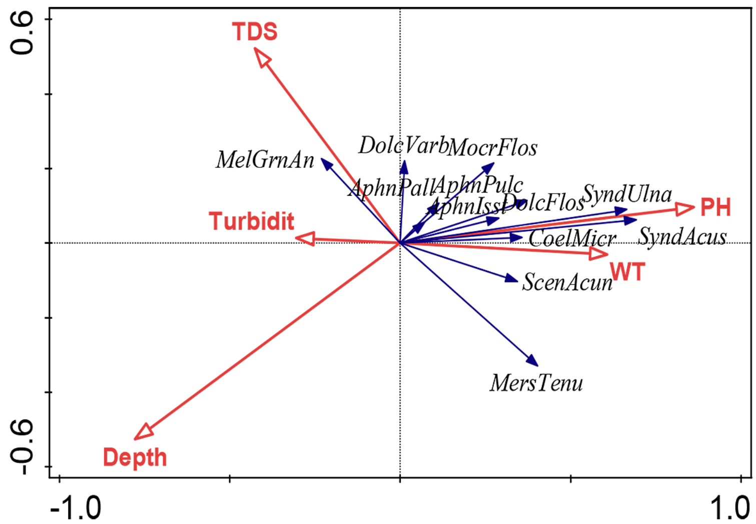

Figure 5. An ordination biplot generated from redundancy analysis (RDA) was used to represent the relationship between physicochemical variables in Nanjiang Reservoir. The variables included turbidity, total dissolved solids (TDS) in mg/L, water temperature (WT) in °C, turbidity (Turb) in NTUs, pH, and depth in m. The ordination biplot also included red arrows indicating significant environmental variables represented by dominant phytoplankton species found in Nanjiang Reservoir

correlation parameters investigated in this study. The relationships identified among dissolved oxygen, pH, nitrogen components, phosphorus, total dissolved solids, and conductivity highlight the intricate interplay of these physicochemical factors within the environmental context of Nanjiang Reservoir.

Correlation between prevalent species and environmental factors

The analysis using CANOCO 5 software had a maximum length gradient of 1.50, which is less than 3, indicating that Redundancy Analysis (RDA) was the most suitable technique for elucidating the relationship between phytoplankton communities and environmental variables in Nanjiang Reservoir. RDA plots demonstrated eigenvalues of 0.156 for axis one and 0.031 for axis two, signifying that these two axes predominantly accounted for the distribution of dominant phytoplankton species.

In Figure 5, it is evident that seven environmental factors underwent significance screening ($P < 0.05$) through Monte Carlo tests. These factors included total dissolved solids, pH, turbidity, depth, and water temperature. Collectively, these environmental parameters explained 21.11% of the dispersal pattern observed in the dominant phytoplankton community. This suggests a notable association between the identified environmental variables and the distribution of prevalent phytoplankton species in Nanjiang Reservoir.

DISCUSSION

Research on phytoplankton dynamics has been proven essential in unravelling the complexities of aquatic ecosystems, providing insights into nutrient cycling, trophic interactions, and overall ecosystem health (Huisman, 2000; Smith *et al.,* 2016). The relevance of phytoplankton as bio-indicators of water quality in Chinese reservoirs has been emphasized by earlier research (Zhang, *et al.,* 2018). The investigation into the temporal and spatial variation of phytoplankton composition and abundance in Nanjiang Reservoir, China, provides valuable insights into the dynamics of water quality in this important freshwater ecosystem.

The phytoplankton community in the Nanjiang Reservoir across the sampling period was dominated by diatoms, contributing up to 58% of the total abundance, followed by Chlorophyta. This is consistent with previous studies in lakes or reservoirs in China which often exhibit the *Bacillariophyta-Chlorophyta* dominance (Liu *et al.*, 2021; Wang *et al.*, 2024; Zhang *et al.*, 2024). The dominance of diatoms in the reservoir points to organic pollution which is known to directly promote their flourishment. Increased concentration of N from organic pollution regulates the population dynamics of diatoms (Wang *et al.*, 2006). This reinforces the usefulness of phytoplankton communities in assessing water quality and informing management strategies in reservoir ecosystems.

Spatial and seasonal variations in the phytoplankton community were observed in the Nanjiang Reservoir. Seasonally, the average phytoplankton density during the summer season exceeded that of the autumn during the sampling period. This indicates that the summer season exhibited a higher abundance of individuals compared to the autumn season. Phytoplankton density and biomass exhibited a similar pattern, with higher levels observed throughout the summer and a decline in the autumn season. These can be attributed to seasonal changes in environmental conditions such as temperature, light availability, and nutrient inputs observed in this study. Studies have shown that phytoplankton often exhibits distinct seasonal patterns, with peak abundance occurring during warmer months when conditions are favorable for growth (Paerl and Huisman, 2009). For example, research conducted in similar freshwater ecosystems has documented increases in phytoplankton biomass during spring and summer months, coinciding with higher water temperatures and nutrient inputs from runoff (Dokulil and Teubner, 2000; Llames *et al.,* 2009). Limited light energy input restricts net primary productivity, and the depletion of algae by grazing herbivores in water cannot be completely replenished (Anneville *et al.*, 2018), leading to a significant reduction in algal biomass during autumn or winter.

Spatially, the phytoplankton diversity was greater in the upstream station than in the downstream station, which is consistent with the results of similar studies (Dou and Zhou, 2022; Wang *et al.*, 2024). This finding indicates variations in the intensity of both anthropogenic activities and rainfall patterns across the reservoir surroundings, which influence the spatial variability of phytoplankton. Similarly, the study observed that phytoplankton density and biomass peaked upstream of the reservoir, particularly at site S4. This is attributed to the sufficient nutrient loadings of total nitrogen (TN), ammonia nitrogen, and Total Phosphorus (TP), which also peaked at the same site from the river's influx. From these findings, it can be asserted that the spatial heterogeneity in phytoplankton distribution within Nanjiang Reservoir is influenced by factors such as hydrodynamics, nutrient gradients, and habitat complexity. These findings correlate with who asserted in their study that phytoplankton communities may vary between nearshore and offshore regions, as well as among different depth zones, due to differences in light availability, nutrient concentrations, and residence times. Also, hydrodynamic processes such as mixing, stratification, and circulation patterns play a critical role in shaping the spatial distribution of phytoplankton, with localized environmental conditions driving community composition and abundance (Padisák *et al.,* 2009).

Investigating the impact of environmental variables such as water temperature, nutrient concentrations, DO levels, and pH on phytoplankton, can provide a more holistic assessment of reservoir conditions and inform adaptive management strategies (Zhang, 2018). Analysis of physicochemical parameters, including pH, water temperature, DO, total dissolved solids (TDS), and nutrients, aligns with previous studies on transitions in reservoirs and temperate lakes (Yuan, 2000; Qu and Zhou, 2023; Wang *et al.,* 2024). The positive correlation between Nitrate-Nitrogen and DO, TDS, pH, water temperature, and Total Nitrogen raises concerns about potential water pollution and increased eutrophication in the reservoir. The Redundancy Analysis (RDA) results revealed a negative correlation between depth and the biological density of many algae, emphasizing the impact of this environmental factor on phytoplankton distribution. Moreover, pH was directly correlated with water temperature and TDS, with RDA results indicating a positive correlation between pH and biological density for most Cyanophyta. The RDA results show that water temperature, pH, and TDS emerge as the primary environmental factors influencing the structure of the phytoplankton community in Nanjiang Reservoir. Notably, this study highlights the promoting effects of pH and water temperature on the prevalence of Cyanophyta within the reservoir's ecosystem, providing valuable information for management of the reservoir's ecological dynamics.

CONCLUSIONS

This study has highlighted the dynamic nature of phytoplankton populations in Nanjiang Reservoir, with distinct seasonal patterns and spatial heterogeneity observed in phytoplankton composition and abundance. The phytoplankton community of the reservoir is mainly dominated by diatoms which points to high organic pollution. The upstream of the reservoir contains the highest phytoplankton density, biomass, and diversity due to the highest concentrations of nutrients from the river's influx. Hydrodynamic processes, nutrient gradients, and localized environmental conditions contribute to this spatial heterogeneity, shaping the community structure of phytoplankton across the reservoir. Seasonal shifts in temperature, light availability, and nutrient inputs drive fluctuations in phytoplankton abundance, with peak blooms occurring during warmer months when conditions are conducive to rapid growth. Redundancy analysis showed the phytoplankton community structure which was closely associated with changes in water temperature, pH, and TDS.

These findings contribute to our understanding of water quality dynamics in Nanjiang Reservoir and may have implications for reservoir management and conservation efforts. By monitoring temporal and spatial variations in phytoplankton composition and abundance in relation to environmental factors, stakeholders can assess the effectiveness of management practices aimed at mitigating nutrient pollution, controlling algal blooms, and preserving ecosystem health. Moving forward, continued monitoring and research efforts are essential for elucidating the drivers of phytoplankton dynamics in Nanjiang Reservoir and informing effective management strategies to preserve water quality and ecosystem integrity. By employing a multidisciplinary approach that integrates ecological, hydrological, and environmental data, stakeholders can work towards sustainable stewardship of this vital freshwater resource for the benefit of present and future generations.

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